Methods and Components for Optical Contention Resolution in High Speed Networks

Prof. Imrich Chlamtac, Principal Investigator
Distinguished Chair Professor of Telecommunications Director, CATSS:
Center for Advanced Telecommunications Systems and Services The University of
Texas at Dallas P.O. Box 830688
Richardson, TX 75083-0688 chlamtac@utdallas.edu
http://www.utdallas.edu/~chlamtac

FINAL REPORT

This project dealt with designing all-optical packet switched networks. In high speed optical networking systems of the day, electronic front ends are used for processing of optical packets at both end-user and intermediate switch nodes. This limits the signaling rate on the optical fiber to almost four orders of magnitude below its Terabits/s capacity. The resulting electronic bottlenecks prevent the full realization of the optical bandwidth from becoming a reality.

Boston's University's part in this consortium consisted of proposing the original architecture of delay lines to effect packet switching, and then to develop the various network protocols, deal with future scalability and provide network evaluation through simulation. All of these tasks have been accomplished successfully, as documented in the semi-annual reports submitted during the project and the key publications included.

The basic idea, originally developed by Dr. Imrich Chlamtac, the Boston University PI, avoids the electronic bottleneck in LAN and MAN topologies by developing and demonstrating a novel optoelectronic receiver front end consisting of optical delay lines and fast optical switches. The proposed approach combined the advantages of optics and electronics in a Switched-Delay-Line Contention-Resolution-Optics (SDL-CRO) to optically store and switch packets. Electronic circuitry, developed by Stanford University team lead by Dr., Katzovsky, driven by inbound signaling, was used to control the storing and routing operations performed by the SDL-CRO. The resulting SDL-CRO functionally is that of a space and time optical switch, hardware developed by GTE team lead by Dr. Melman, which allows packets contending for a common resource to be redistributed over time and space. This provides a unique mechanism for dealing optically with the key problem of contentions that has, so far, only been dealt with in switching systems electronically.

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By allowing the data to be retained in the optical domain, the O/E and E/O data conversion of conventional fiber-based networks is not necessary. This in turn makes it possible to use WDM techniques to multiplex several high speed data streams onto the optical fiber, without requiring prohibitive parallel signal processing to realize the electronic buffering at intermediate nodes. As a result, the throughput potential of the network may be increased by orders of magnitude.

Another advantage is the CRO's node localized principle of operation which makes it usable in a variety of architectures and network topologies. The CROs only require locally available information at the node, i.e., the set of packets in the switch, their respective destinations, and their current slot in the switch. Local resolution of the contention problem avoids critical booking of the other nodes' activities as is required by distributed algorithms.

In short, the SDL-CRO offers the significant advantage of contention resolution in an all optical format and could become a key component for an ultra fast, multigigabit/s, all-optical network.

The basic concept:

In the contention resolution approach developed by Dr. Chlamtac The information arriving on a single fiber at a node of a WDM-enhanced high speed network contains multiple channels carrying merged streams of packets statistically distributed in time. This gives rise to occasional time-slot overlap among packets arriving from different streams at the receiver and subsequent loss of contending packets. The use of delay lines to shift contending packets by one or more time slots, can reduce or virtually eliminate the packet overlap, i.e. contentions. This original idea has been developed and evaluated while Dr. Chlamtac was at the University of Massachusetts. In order to perform this operation on a packet-by-packet basis, fast optical 2x2 switches must be used to allow fast device reconfiguration. The net result of this switched delay line strategy, controlled by the local node intelligence, is the interleaving of the packet streams into a single, contention free, channel of information with no loss of packets.

By significantly reducing the amount of contentions, SDL-CRO reduces: a) packet retransmission rate; b) packet deflection probability; and c) buffering requirements. Reducing retransmission and deflection probabilities increases throughput and decreases end-to-end packet delay. %Resolution of the contention problem local to the node avoids critical booking of other nodes' activities as is required by distributed algorithms. This allows implementation of optimal sharing techniques at each node independently. The local resolution of conflicts in SDL-CRO also leads to a higher robustness and easier realization of protocols. Since SDL-CRO is a local solution to resource contention it is also suitable for being applied to several existing network solutions to improve their functionalities, without requiring a drastic redesign of the system.

In this project we have also demonstrated network performance improvement obtained through the application of SDL-CRO. To demonstrate a network performance improvement we focus on two extensively used topologies found in existing and proposed optical communication systems: Star and Ring. WDM stars constitute a good solution for a very high speed network when the number of wavelengths is equal to the number of nodes, i.e. a dedicated channel can be assigned to each node so that no collisions of packets occur at the hub. When the number of wavelength is smaller, transmissions need to be coordinated to avoid collisions on each shared wavelength (channel). In a high-speed system in which propagation delay penalty may be orders of magnitude greater than packet transmission time, this coordination is a severe technical/performance problem. A WDM ring topology allows for an elegant solution of the collision problem to be obtained locally at each node. As traffic of up-stream nodes is passing through the node, collisions can be avoided by simply transmitting new packets in empty slots. Moreover, if packets are extracted from the network by their destination nodes, the capacity of the ring is twice the capacity of a star (under channel sharing condition) due to spatial diversity reuse of wavelength channels. In either topology we consider systems with a common clock in which time is divided into fixed slots, whose duration equals the packet transmission time plus a guard time interval. Transmitted signal is synchronized and each node knows the destination of the arriving packets as discussed in preceding sections. Every node can then select one packet for reception in each slot, losing all others due to contentions. These receiver contentions can be avoided using SDL-CRO.

In summary, during this project the Boston University team lead by Dr. Chlamtac made the following discoveries and accomplishments:

Developed control strategies and protocols for CRO (node) and network operation.

Developed policies for multi-channel selection control.

Developed SDL-CRO and node transmitter and receiver control algorithms.

Established set of network performance test procedures and evaluated the network performance.

Participated in architectural design of the network testbed.

Participated in testing network performance of the discrete-component SDL-CRO star network testbed.

Participated in the node interface design.

Performed buffer sizing and management.

Evaluated system scalability (to more nodes and/or wavelengths)
assessment based on previously established theoretical analysis tools and
optical and electrical experimental data from the testbeds.

Designed protocol development and network evaluation
software and applied it to the network design and evaluation process.

KEY RESULTS IN PUBLICATIONS:

I. Chlamtac, A. Fumagalli, and C. J. Suh, ``Multi-Buffer Delay Line Architectures for
Efficient Contention Resolution in Optical Switching Nodes" to appear in IEEE
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I. Chlamtac, A. Fumagalli, and R. Grasso, "A Scalable, Self-Adaptive and Distributed
Fair Access Control for WDM Bus Network" ONDM'99, Paris, France, February, 1999.

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Multiplexer, IEEE GLOBECOM'97, Phoenix, Arizona, November 1997.

I. Chlamtac, M. J. Ciesielski, A. Fumagalli, C. Ruszczyk, and G. Wedzinga, " Intelligent
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I. Chlamtac, A. Fumagalli, and C.J. Suh, ``A Delay Line Receiver Architecture for All-Optical Networks'', IEEE INFOCOM, San Franciso, CA, March 1996.

I. Chlamtac, V. Elek, A. Fumagalli, and C. Szabo, ``A Scalable Optical Packet Switching Network Architecture'', 7th IEEE Workshop on Local and Metropolitan Area Networks, Marathon, Florida, March 1995.

M. Cerisola, I. Chlamtac, A. Fumagalli, R. T. Hofmeister, L. G. Kazovsky, C. L. Lu, P. Melman, and P. T. Poggiolini, ``Ultra-Fast Clock Recovery and Subcarrier-Based Signaling Technique for Optical Packet Switched Networks'', Summer Topical Meeting on Optical Networks and Their Enabling Technologies IEEE-LEOS, Lake Tahoe, CA, July, 1994.